The Effects of Radiation on the Resonant Frequency of a Polysilicon Microstructure

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ABSTRACT

A mechanical microstructure was exposed to 10 Mrad of Gamma Rays from Cobalt-60 source to examine the effects of possible lattice damage upon the Young's modulus of polysilicon. Resonant frequency was measured prior to and after testing to detect both shifts in Young's modulus and the accumulation of trapped charges in the actuators. The test showed no change in the resonant frequency or Q factor, and thus Young's modulus is shown to be not affected by gamma radiation and the theory of accumulation of charged particles in dielectrics is corroborated.

INTRODUCTION

Based upon the work of Edmonds [1] and Knudson [2], it is apparent that large doses of radiation will impact the performance of MEMS systems. Since radiation tolerance is critical for using MEMS systems in space, it is important to isolate radiation related failure mechanisms. Edmonds, et. al. conjectured that the build up of charge across dielectrics is responsible for the degradation in performance of devices with exposure to radiation. This experiment was run to attempt to isolate the mechanical structure of a device and see if radiation would induce changes in devices without dielectrics. The device used for this test is shown in Figure 1.
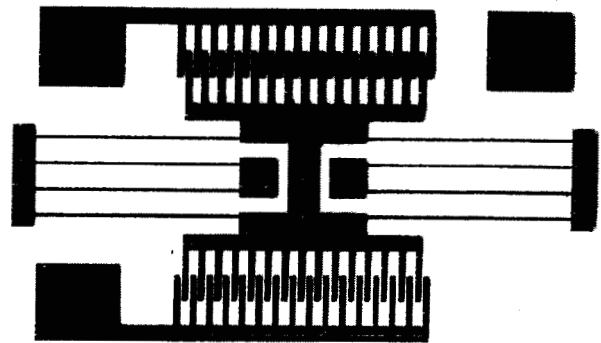

Figure 1: Structure used in this test

This resonator was fabricated at Sandia National Laboratories. It was micromachined from a 1 μm thick polysilicon layer. As part of the processing of this device, it was immersed in 49% HF to remove all dielectric materials, so that a floating polysilicon mass was left. The device was coupled to two comb drives, which were used for both actuating and measuring resonance on the device.

THEORY

Radiation is known to make materials more brittle. However, the effects of radiation upon a thin films of brittle materials, such as polysilicon, are not as well known. For this reason, this test was designed to examine the possible embrittlement of polysilicon. The elasticity of a material is quantified by Young's modulus. To measure Young's modulus, the resonant frequency of the structure was measured.

In mechanical systems resonant frequency is determined by the relationship:

$$\omega_0 = \sqrt{\frac{k}{m}}$$

where k is the stiffness of the structure and m is the mass. For this particular test structure, the resonant frequency has been analytically determined as: [3]

$$\omega_0 = \sqrt{\frac{2Eb(a/L)^3}{M_p + 0.3714M_b}}$$

where E is the Young's modulus, a is the width of the cantilever beams, b is the height of the beams, M_p is the mass of the center structure, and M_b is the mass of the cantilever beams. This shows that a shift Young's modulus will result in a change in resonant frequency to the one half power.

Another possible effect of radiation is the accumulation of built-in charge. This effect would not be expected in these structures due to the fact that they are made entirely of polysilicon, as all of the SiO_2 was etched off prior to testing. However, if charge were to become stored in the device, it would result in a built-in electric field. This internal electrostatic field would then lower the stiffness of the structure.[4] If this occurred, it would be revealed as a lowering of the resonant frequency.

Since this test measures a change in resonant frequency, it was not of paramount importance to extract the initial Young's modulus from the structure, as it the important quantity in this experiment is ΔE, not E.

As part of this experiment, the dampening effects of radiation will be calculated. Structural dampening can be calculated by measuring the Q factor of a structure. The structural dampening factor, ξ, can be determined from Q by the relation:

$$Q = \frac{1}{2\xi}$$

Thus by measuring Q, which is defined as the ratio of resonant frequency to the frequency range that has a response greater than $1/\sqrt{2}$ times the maximum response, it is possible to determine structural dampening.[5]

EXPERIMENTAL

Prior to testing, the structure was kept in a vacuum chamber to prevent environmental contaminants from impinging device operation. After being removed for the test, one side of the structure was connected to a function generator

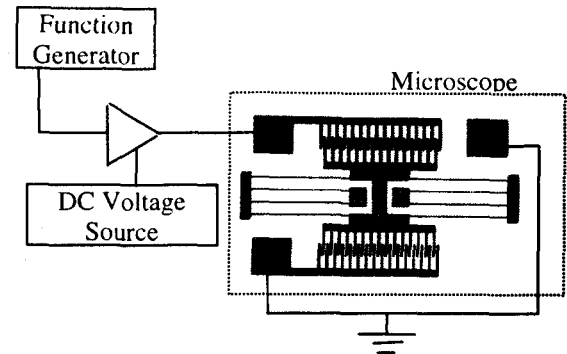and power amplifier, while the other pad was connected to ground.

Figure 2: Diagram of testing apparatus

Since this structure has extremely low capacitance, it was decided that the best method to determine resonance was optically rather than electrically. This was done by applying a square wave of 40 V_{p-p} to the structure and sweeping the frequency. At resonance there was a marked change in displacement that was easy to characterize, as shown in Figures 3 and 4.
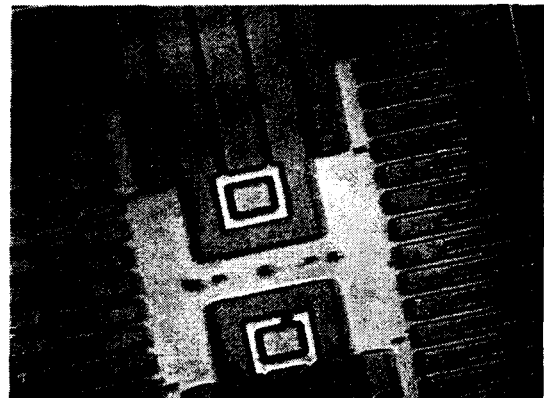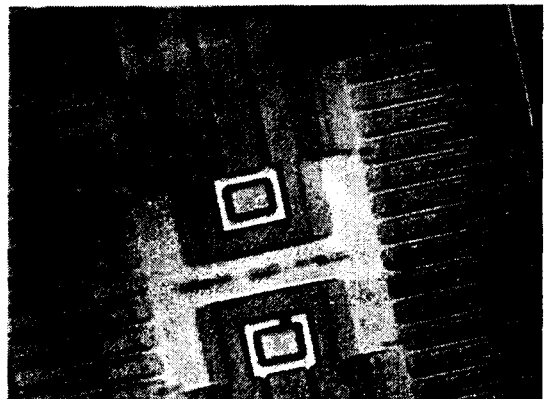

Figure 3: Device operating at 12150 Hz

Figure 4: Device operating at 15150 Hz. As can be seen, displacement is amplified noticeably at resonance.

The resonant frequency of the device was measured prior to testing. Measurements were also taken at 70% of maximum displacement for the determination of the Q factor of the structure. After this data was collected, the sample was grounded and placed 18cm away from a Co-60 source, which produced a radiative flux on the device of 100 rad/s. The device was exposed to the source for 1×10^5 seconds, or roughly 28 hours, in order to have a total accumulated dose of 10 Mrad.

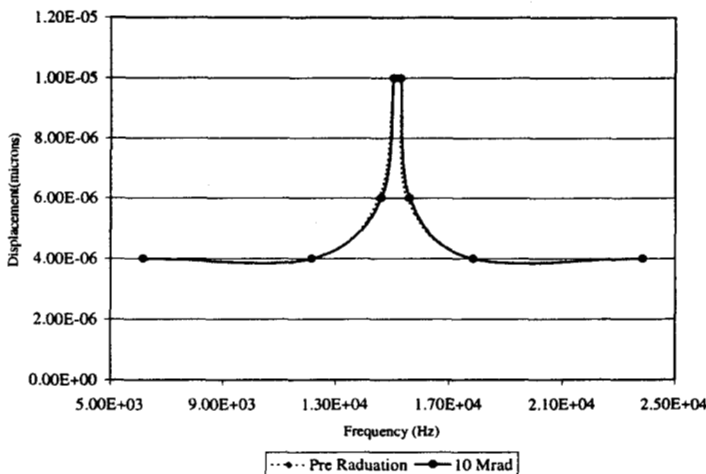After the test, the device was tested again for resonance. The results of the test are shown in Figure 5.

Figure 5: Frequency response of the structure before and after exposure

RESULTS AND DISCUSSION

As Figure 5 shows, there was no significant change in resonance as a result of the tests. Both tests revealed a resonant frequency of 15150 Hz, with 70% bands at ±500Hz. This means that the effect of 10 Mrad of radiation was not measurable.

The Q factor of the structure was also calculated to look for changes in dampening due to radiation. Although a change in Q must also be accompanied by a shift in resonance, which did not occur, Q was calculated for the device to be 15150/1000 or Q = 15. [5]

The structure did not show demonstrate either a raising of resonance due to embrittlement nor did it show a lowering of resonance due to built in charge. While the latter result was expected for this conductive structure, the prior result was somewhat surprising, as the structure was bombarded with extremely large doses of Gamma rays, which would have presumably caused a great deal of lattice damage. However, these results indicate that the effects of the radiation were insignificant for device operation.

CONCLUSION

The results of this test should confirm that high doses of radiation have no effect on the Young's modulus of polysilicon. Also, as expected, there was no charge accumulation that would have altered the resonant frequency of the device, which validates the theory that charge trapping in dielectric layers is the dominant reliability concern in MEMS structures. This result would seem to indicate a method for designing radiation tolerant MEMS structures. Since, without a dielectric, there was no measured change in device operation, it would seem that limiting the use of dielectrics in device design is one method of radiation hardening MEMS device.

ACKNOWLEDGEMENTS

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